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ABSTRACT

This part of the School Management Handbook provides elementary school administrators with an overview of recent developments in educational technology. Particular attention is paid to information needed when selecting computers for educational purposes. The first section considers the role of educational technology in general and touches on the implications of today's technological revolution. Focusing on the use of video, section 2 notes new methods for resolving the old problems of fixed broadcast schedules and inadequate program quality, then discusses the potential roles of videotape and videodiscs in education. Section 3 analyzes the place of calculators in the classroom, recounting the objections to calculator use and describing the educational functions of calculators, supportive materials, teacher preparation, and calculator selection considerations. The last three sections treat computers in education, covering such topics as software and courseware selection, educational uses for computers, computer languages, computer literacy, teacher involvement in computer oriented education, computer hardware, the basic parts of the computer, computer memory, administrative uses of computers, and computer peripherals such as storage devices, printers, intermachine communications equipment, and sound equipment. Each section of the document includes recommendations for school policy on using and selecting technological devices and materials. (PGD)

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SCHOOL MANAGEMENT HANDBOOK

The New Technology in Education

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Educational Technology: Introduction

Video

Calculators

Computers: Software

Computers: Hardware

Computers: Peripherals

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Grand Forks, North Dakota

Editors

Warren T. Greenleaf
Marilee C. Rist

Consultant

Mitchell Lazarus

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5.1 EDUCATIONAL TECHNOLOGY: INTRODUCTION

SUMMARY

The technologies being newly applied to education are qualitatively different from those of the past.

BACKGROUND

Educators are a cautious lot where technology is concerned, and rightly so. Professional errors of judgment carry high costs in human terms. The past few decades are strewn with technologies that failed to deliver on their expansive promises. Educators remember all too well the teaching machines, the early forms of computer-aided instruction, and countless novel devices for film, filmstrip, and audio. Each arrived in a flourish of publicity and high expectations, only to gather dust just a few years later in the school storeroom.

There is not now, and there never can be, a universal educational panacea--a technological contrivance that will solve every educational problem once and for all. The most that a technology can do, and the most that anyone should expect of it, is to help a teacher teach, either by aiding in presentation, as a filmstrip projector, or by standing in for the teacher occasionally, as a computer. To meet the latter goal--and it is an ambitious one--any technology must meet certain requirements:

1. Students should learn from it.
2. Students should learn what teachers think they ought to, not what the technological developers can most easily work with.
3. Most students should find the learning process interesting most of the time, or the first two goals cannot be met.
4. What the device teaches should always be under the teacher's ultimate control.
5. The technology must not increase the net demand on teacher energy. That is, it should be no harder to teach with the device than without it, taking into account whatever preparation and support the teacher needs to use the device.
6. The technology must not add to the burden of classroom management.

These six points add up to a tall order--more than the technologies of the past could achieve.

Educational Technology: Introduction--5.2

THE NEW TECHNOLOGIES

There is a curious and little-appreciated fact about technology generally: the more advanced and complex it becomes, the easier it is to use. Consider the automobile. For decades after its invention, while it remained a relatively uncomplicated machine, to start and drive an automobile took physical strength, mechanical skill, and a sound knowledge of its workings. By the 1950s, when the car had evolved into a hopeless tangle of wires, hoses, automatic this, and power-assisted that, it was possible to drive one with little physical effort, and without the remotest idea of how it works.

For the first time, computers are achieving that kind of horribly complex simplicity. It is now possible to remove a computer from its box, plug it in, and put it to effective use inside half an hour or so--just about as long as it takes to figure out all the switches in a new car. With its electronic equivalents of power steering and automatic transmission, the modern microcomputer frees the user to watch the scenery, so to speak; the machine can take care of its own mysterious needs.

For education, that much is necessary, but it is far from enough. A computer cannot teach. Only people can teach, a homily left untouched by a lot of fancy electronics in a box. People teach by example, by explanation, by encouragement. Now, however, there is another way for people to teach: by writing computer programs that teach by example, by explanation, and by encouragement.

The modern approach, it must be stressed, has little to do with the computer-aided instruction of the 1960s. That effort missed anywhere from four to six of the points above, depending on who does the reckoning. The difference? Computers have become a lot smarter in the past twenty years. In consequence, smart people can now use them a lot more effectively to help teach children.

A great many people, some educators among them, harbor against computers what can best be called a prejudice. Others show an uncritical enthusiasm. Both attitudes are understandable, and both are equally impeditive. If indeed the computer is a helpful educational device, capable of delivering benefits in excess of all its costs, then it belongs in the classroom. We need, to paraphrase Einstein, all the help we can possibly use, but not more.

This issue of the *Handbook* gives the information that educators need to make sound decisions about computers. It also addresses two other technologies in less detail, because there is less of importance to say about these: video and calculators.

Educational Technology: Introduction--5.3

McLuhan tells us that any medium, quite apart from the particular message it may carry, has its effects on those who use it. In some transcendental sense he is doubtless right, but that is no starting point for educational decisions. A television set in the classroom, like a computer, can be no more effective than the program it carries. The problems in educational television have always been twofold: first, making good programs, and second, delivering them to the classroom at the precise time when they can be most useful. Here the new technologies of direct-access cable and videodisc may be of practical help.

Calculators, for their tiny size and all but negligible cost, promise to have a disproportionate impact in certain subjects on the goals and methods of education. Perhaps for that reason alone, their adoption has run into a firestorm of controversy--greater, the surveys tell us, than the debate over computer use. Once again, the problems lie not in the device, but in learning how best to use it for teaching.

The pages that follow explore these issues. It is always tempting to wander off into the possibilities of the future. Often they are more interesting than the tame realities of today. Nonetheless, there are times when that temptation must be set aside. With few and well-marked exceptions, we deal here with the technology that is on the shelf today, and ready for use in the classroom by first thing Monday morning.

5.2 VIDEO

SUMMARY

Emerging technologies may help to overcome some of the obstacles that have kept educational television from reaching its full potential in the past.

BACKGROUND

Almost from the date of its invention, television was hailed as a boon to educators, a device that "brings the world into the classroom." There have indeed been conspicuous successes; but by and large, educational television has not lived up to the early expectations. Today, once again, recent technological developments are renewing the old promise.

Two major problems have held television back: the sometimes insurmountable inconvenience to educators of fixed broadcast schedules, and the difficulty of providing good programming.

VARIABLE SCHEDULING

In the early days, schools that wanted to use educational television had to accommodate the school day to the broadcast schedule. Often that was impossible. In an effort to solve the problem, some districts set up their own transmitters and ran the same programs at several times during the day. But limitations on channel space generally required these to be low-power UHF transmitters, which often gave poor reception. And, as programs became available faster than money for transmitters, the scheduling problem resurfaced.

Cable offered better reception on more channels, but at high installation cost. Some jurisdictions, in granting commercial cable franchises, required the successful bidder to wire up the schools, and sometimes also to provide the "head end" equipment needed to send programs over cable. Again, the goal was to put each program into the classroom at many different times, so that teachers could use the material at their own pedagogical convenience. Where it is available, cable can be an enormous help.

The invention of inexpensive videotape recorders in principle should have solved the scheduling problems once and for all. Schools could build their own tape libraries, taking programs off the air and from cable, and use any program at any time. But it

has not worked out that way. For one thing, early video recorders were unreliable and tricky to operate, so that few teachers felt comfortable using them. For another, the copyright laws in effect bar do-it-yourself tape libraries.

The new generation of videocassette recorders has removed most of the technical problems, but the copyright laws still prohibit keeping an off-the-air tape for longer than seven days (see below). Short-term scheduling shifts are possible; a teacher may use a Monday morning program on Friday afternoon. But this does not help the teacher whose students are ready in November for a program broadcast the preceding March.

Two solutions to the long-term scheduling problem still lie in the future. One is a cable system on which the teacher can dial up any program at any time. The technology is at hand, and a few localities are using it; but such a system is expensive, and it must pay royalties unless the producer waives them. The second solution lies in videodisc. Again, the technology is ready, but the programming is not (see below).

EDUCATIONAL PROGRAMMING

Many educators tend to underestimate the difficulty and cost of making good educational programs. The earliest approach was simply to aim the camera at a good teacher, but the resulting programs were stiff and boring. Still hampered by inadequate budgets, producers turned next to studio actors, puppets, and on-location film, but these products, too, failed to compete with the expectations children had derived from watching glossy commercial television. Without the child's full attention, educational goals suffered.

The first major break with these limited approaches came with "Sesame Street." The program offered three major innovations. First, and perhaps most important, it drew its production staff from commercial television, not from educational television. Second, it unashamedly modeled its segments after television commercials--which parents, to their rue, had long known to be highly effective teaching devices. Third, the program put a very high priority on entertainment value. A segment that failed to hold children's attention, no matter how valuable educationally, did not get on the air.

"Sesame Street" has been the model for almost every educational program since--in all respects but one. That kind of television is extraordinarily expensive, and few other producers have enjoyed the necessary budgets. Today it is difficult to produce a studio segment for less than about $2,000 per minute of finished product. Animation, preferred by children and educators alike, can easily run to $10-20,000 per minute.

Owing to its high production costs, educational television faces the same basic problem that commercial television does: a program without a sufficient audience cannot justify its expense. New delivery systems, such as those offered by advanced cable systems and videodisc, can target existing programs to particular classrooms better than the present methods do. By reaching larger fractions of each particular audience more precisely, they may also help to support programs that can better address the needs of particular groups within the overall student population.

VIDEOTAPE RECORDING

Schools use videotape for three major purposes: (1) to record programs off the air or from cable; (2) to show videotapes purchased or rented commercially; and (3) with a camera, to aid in certain educational and extracurricular programs for students and for practical teacher education.

Historically, videotape has used a variety of mutually incompatible formats, a fact that has impeded development of the industry. There are at present five distinct videotape formats in use for educational purposes:

- three-quarter-inch reel-to-reel
- half-inch reel-to-reel
- three-quarter-inch "U-Matic" cassette
- VHS videocassette
- Betamax videocassette.

A tape made on any particular machine can be played back only on a machine that uses the same format.

For all but a few specialized purposes, the first three formats are obsolete. Most commercial tapes nowadays are distributed on VHS or Betamax, which are also good choices for recording off the air. Both give adequate picture quality. Players, cassettes, and service for the two types are widely available. VHS will take a maximum six-hour tape, as compared to Betamax's five hours--a difference that is important in the home market, but less so for educational uses. Otherwise, on technical grounds, there is little to choose between the two.

Virtually everything broadcast is copyrighted, and it is a violation of the law for most people to record a copyrighted television program off the air or cable. Congress wrote a special section into the law for educators, however. A nonprofit institution such as a school can record programs sent by a "noncommercial educational broadcast station." This includes the local PBS outlet, along with state, district, and consortium stations. There are two restrictions. First, the tape can be shown only

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"in the course of face-to-face teaching activities...in a classroom or similar place devoted to instruction." Running last night's movie in the teachers' lounge, for example, is not a valid use. Second, the recordings can be used "for a period of no more than seven days from the date of the transmission...and must be erased before or at the end of such period." 17 U.S.C. § 118(d)(3). Everyone involved with the law recognizes the hopelessness of enforcing the seven-day requirement.

Some schools use video cameras in conjunction with their videocassette recorders. Color cameras tend to be expensive, but black-and-white suffices for most educational purposes. Any camera purchased should be compatible with all of the school's recording equipment. It should have a built-in monitor--a small screen on which the operator can see the picture while taking it. Use of a separate television set as the monitor is very awkward.

Portable, battery-powered machines are available in both VHS and Betamax formats for use with cameras. They tend to be somewhat less sturdy than the nonportable models, and ordinarily offer little advantage except to the physical education staff, who can take the unit into the field. In addition, portable units are easy to steal.

Each videocassette recorder should be kept on a cart equipped with wheels, since much of the damage to these machines occurs in the course of moving them from one room to another by hand. The recorder can be bolted to the cart to help discourage theft. Some carts have a separate upper platform to carry the television set. These are top-heavy when fully loaded, and can easily tip over onto a child. It is better to remove the television set before moving the cart.

Most videorecorders attach to the television set's antenna terminals. Used this way, the recorder has to raise the picture signal to television broadcast frequencies, and the television set translates it back down. Some sets, made especially for use with recorders, have an input marked "video" that takes the picture signal at much lower frequencies. Although they cost a little more, these sets give a better picture. A switch allows them to receive conventional television programs as well.

Teachers can handle cassettes most easily when each carries only one program. The shortest possible cassette is the most economical. When buying blank cassettes for a videorecorder, it is wise to avoid the very cheapest, as some of these have a tendency to misfeed and jam. If a tape will be played a great many times--more than a hundred or so--a cassette of very good quality will be more economical over the long run.

VIDEODISC

For about ten years, videodisc has been "just around the corner." So far as most

educators are concerned, it is still just around the corner.

There are three videodisc formats in use. As with videotapes, a particular disc will work only on the type of player it was made for. It is too soon to tell whether all three types will remain in production; thus, choice of the wrong player can leave a school with a useless machine a few years hence. No present videodisc system can record programs; they only play back prerecorded material.

All three systems give a much better picture than do videocassettes, and discs produced in quantity cost less than prerecorded videocassettes. Each disc plays for either 30 minutes or an hour per side. One system is especially well suited to educational uses: it can show a continuous half-hour program, or any one of 54,000 separate still pictures, or any combination of these. This format is the most expensive, however, and it is not doing well in the home market, where it must succeed to survive.

At present, with relatively few players in use, most of the discs in production are those with the widest appeal, chiefly popular films. The only educational materials becoming available are certain previously broadcast programs with educational value. In view of the scarcity of materials and the uncertainties as to which formats will prevail, it is probably too early for most schools to invest in videodisc equipment.

One development still to come, but with intriguing educational possibilities, is the marriage between videodisc and computer equipment. (See also Sections 5.4 and 5.5.) Two forms are being tried. In one, the videodisc does not hold television programs. Instead, it becomes an enormous "memory" for computer programs. The capacity is immense: one side of one disc can hold about 100,000 separate educational computer programs, each of them as long and complex as anything on the market today.

In the other form of the marriage, which may be a little farther off, the videodisc player shows television images on the computer's screen, under control of the computer. Instead of merely having the child read from the screen, the computer's instructional material can consist of picture and sound. Through the computer, what the child sees and hears from moment to moment can depend on his previous responses. This makes it possible to tailor the educational experience to the child's immediate level of understanding.

The equipment for these developments is presently available. The task of making educational programs that use the equipment creatively and wisely enough to justify the cost is proceeding much more slowly.

Video--5.10

RECOMMENDATIONS

1. Most schools can make good use of videocassette equipment. Choose either VHS or Betamax, and buy from a local, reputable dealer. Educational discounts are often available.
2. Any television set will work with a videocassette recorder. For the best possible picture, use a set with a separate "video" input. Ordinarily, however, it is not worth buying new sets for this feature alone.
3. If buying a camera, make sure that it will operate properly with any recorder that the school uses. Color cameras may not be worth the considerable extra cost.
4. Middle-quality videocassettes are adequate for most purposes. Very inexpensive cassettes may jam, and can leave debris on the recorder heads that shortens their useful life. It will save money over time to record programs that will be played very often on cassettes of the best quality.
5. Do not buy a videodisc player without first investigating available programming.

5.3 CALCULATORS

SUMMARY

Electronic calculators are inexpensive and reliable devices with great educational potential; yet their routine adoption for classroom use has been preceded by a decade of controversy.

BACKGROUND

When calculators first appeared ten years ago, they cost hundreds of dollars, and for that reason were educationally impractical. The electronics industry projected dramatically lower prices to come. Nevertheless, many educators were caught by surprise when the prices went below ten dollars within just a few years, a decline unprecedented for any consumer item.

The drop in cost and the parallel increase in quality coincided, however, with the rise of the back-to-basics movement. In mathematics, where back-to-basics stresses traditional arithmetic drill, advocates of the movement looked upon calculators with great suspicion. Even the appearance of a large body of research showing consistently that calculator use does not impair children's skill in rote arithmetic failed to dampen the controversy. Only since about 1980, with the acquisition of at least one calculator by virtually every American household, has the classroom use of calculators become relatively unremarkable.

OBJECTIONS TO CALCULATOR USE

Those who oppose calculators in the classroom have most typically done so on the following grounds. The passage of time has removed certain of these objections, but some remain valid.

1. *Cost.* Even six or seven dollars per calculator can add up to a lot of money, when multiplied by a number of calculators sufficient to equip a classroom, a school, or a district.
2. *Discrimination.* Earlier, when calculators were more expensive, a prominent civil rights group took the position that calculators would give an advantage to affluent children, among whom minorities are under-represented. The price reductions since then have largely abated this concern.
3. *Attrition of basic skills.* The use of calculators in school was thought at one

time to undermine children's acquisition of the traditional arithmetic skills. Almost unanimously, however, several hundred research studies have shown this not to be the case. About half the studies show calculator use to improve manual skills, while the remainder show no significant effects either way.

4. *Dependence.* Closely related to the preceding objection, this one stresses that children who come to depend on calculators in school will thereafter be mathematically helpless without them. Calculator advocates respond that students need not become dependent in the first place; that calculators and other aids to computation are everywhere; and that even before calculators appeared, few adults could do much longhand arithmetic anyway.

5. *Theft.* Despite early fears, theft of calculators by children is not widely reported to be a problem.

6. *Maintenance.* Although problems with maintenance have accompanied every educational technology to date, calculators appear to be the first major exception. Well-built units rarely break down, and when they do, they are inexpensive enough to replace outright.

7. *Batteries.* Early "LED" calculators were hard on batteries, requiring frequent replacements. The newer "LCD" calculators can run on the same battery for years, and thus have greatly eased the replacement problem.

8. *Lack of teacher acceptance.* As teachers gained familiarity with calculators in their personal lives, many came to appreciate their potential in the classroom. Surveys show that acceptance by teachers and principals depends on grade level and purpose, being greatest when used with older children and for the teaching of basic skills.

9. *Lack of suitable curricular materials.* This remains a problem (see below).

10. *Lack of teacher preparation.* Also still a problem (see below).

USES FOR CALCULATORS

In the relatively few years since their first appearance, four major categories of educational use for calculators have emerged, with countless variations on these.

The least controversial use, and the only one widely accepted from the beginning, has children using the calculator to check their answers from manual computation. Although some teachers report that the practice aids motivation, the research evidence is mixed. It may be that the speed, ease, and accuracy of the calculator make the tedious longhand methods seem pointless by comparison.

A second use, one widely accepted today, allows students in middle and secondary school to use calculators for routine computations in subjects other than mathematics, most often physics, chemistry, and social studies. By saving time, this practice allows students to work through more problems using more realistic data, and to experiment with different approaches to a solution. Some critics argue, however, that it removes one of the few excuses for exercising manual arithmetic skills in school.

The third use, still controversial, employs calculators as a tool for exploring number concepts in the early grades--for example, in examining the relationships between common fractions and decimal fractions. Although discussed frequently in the professional journals, this application has received little formal research, and there is a dearth of suitable curriculum materials.

The fourth use is potentially the most important: as an aid in the teaching of problem solving. Mathematics educators in the past few years have shown a renewed interest in problem solving, and in calculators and computers as problem solving tools. The current emphasis is not so much on traditional word problems as on more creative and heuristic forms of problem solving, an approach to which calculators are ideally suited by their speed and flexibility. Again, however, curriculum materials have failed to keep up with educators' interests and priorities.

CURRICULUM MATERIALS AND TEACHER PREPARATION

The main drawbacks to routine, widespread calculator use in the schools today are an insufficiency of appropriate curriculum materials and inadequate teacher education in connection with calculators.

Most of the newer textbook series in mathematics have "calculator exercises" at the end of some sections. Typically these are problems identical to those that students have just worked by hand, using slightly more complicated numbers; they show no special educational value. No present series integrates calculator use into the curriculum sequence itself. Most educators working in this area agree that curriculum integration is necessary to calculators being used to their full potential.

The publishers' reluctance to take calculators fully into account stems from their belief that the schools are not ready for such a curriculum, as evidenced by the fact that most schools use calculators only supplementally. Some school people, however, argue that their use of calculators is supplemental only because integrated curriculum series are not available. The present situation is something of a stalemate, likely to persist until the publishers sense more educator interest in calculators than they do now.

Calculators--5.14

Teacher preparation presents a similar problem. There are few systematic programs on calculator use, either inservice or preservice, because of a perceived lack of interest among teachers--yet, as one reason for not using calculators more, teachers point to the lack of programs to help them.

These problems tend to be less acute in the secondary grades, where mathematics teaching tends to be more specialized. Teachers feel greater freedom to write their own materials, invent their own techniques, and experiment. Calculators have also received a warm welcome in nonmathematical secondary subjects, particularly the sciences. In those subjects, where the calculator merely stands in for longhand computation, a lack of special materials and teacher preparation becomes less important.

CHOOSING CALCULATORS

There seems to be general agreement on this advice: choose simple calculators of fairly high quality.

Calculator prices are lowest among the basic four-function units and go up rapidly with the addition of extra features. Most such features--such as memories, square root keys, and percent keys--are unnecessary for most applications. (One exception: physics students will need the square root key and possibly the trigonometric functions as well.) The extra keys can also cause a great deal of confusion for both teachers and students. Some operate differently on machines from different manufacturers, so that two students pressing the same keys on different machines can arrive at different answers. For elementary school students, a four-function machine is usually the best choice.

Machines from reputable manufacturers tend to be more durable than those of uncertain origin. A few dollars more per unit initially may save a great deal in replacement costs. Service is not much of an issue, as the cost of merely transporting a calculator for repair often exceeds the cost of a new one; but newly purchased calculators should carry a warranty that will be honored locally.

For school use, "LCD" calculators are best: those on which the numbers appear in black against a silver background. The older types, with red or green numbers that light up, require battery replacement much more frequently. Quantity purchasers can insist on fresh batteries in all units delivered. Factory-installed batteries, especially in machines from overseas, may have lost much of their useful life before the calculator arrives at the school building.

Try out any calculator considered; do not merely order from a catalog. Look for a bright, contrasty display. The keys should feel crisp, not mushy, preferably with a little "snap" as they hit bottom. Make sure that the door to the battery compartment is firmly attached. A good calculator will survive several drops to a wood or tile floor without opening, and will still work properly.

In the elementary grades, plan on one calculator for about every three or four students. Depending on the application, secondary school students may need more.

IMPLICATIONS FOR THE FUTURE

The spread of calculators through American homes and businesses, even more than the spread of computers, has important long-term implications for the elementary curriculum. These implications fall into three major categories.

First, certain of the current topics in elementary mathematics instruction have lost much of their practical utility. Few adults nowadays compute lowest common denominators or long division by hand. Some educators have questioned whether such topics still warrant the enormous time investment that their teaching requires. They argue that, much as the manual extraction of square roots disappeared from the curriculum a generation ago without apparent harm, other topics may safely be dropped soon.

Second, intelligent use of a calculator requires other skills that are not presently part of the elementary curriculum. Sometimes summarized as "number sense," these have to do with estimation, accuracy, precision, order of magnitude, scaling, and the like. As calculator use gains ground, these topics are likely to find gradual inclusion.

Third, as mentioned above, calculators open new approaches to the teaching of problem solving. They allow the use of realistic data even in the very early grades, and they permit far freer experimentation than manual calculation does.

The major organizations concerned with mathematics education have all endorsed these three kinds of changes, though they approach the deemphasis of manual computation with caution. Some experts predict that major changes to the elementary curriculum will result within the next ten years or so.

RECOMMENDATIONS

1. Even where it is not officially sanctioned, surreptitious use of calculators by teachers is widespread. This is probably the worst of all possible outcomes. It is better, in general, to have a workable policy that encourages calculator use for particular purposes.

2. Teacher involvement in formulating such a policy is extremely important. Any policy without such involvement is likely to meet resistance.

3. Parents often feel strongly about the calculator issue. It is usually wise to inform parent groups early, and to receive their opinions before putting a policy into effect. If parents first hear of calculators in the school through their own children, a disproportionate amount of trouble may ensue.

4. Encourage the initiation of inservice workshops on calculator use.

5. If you use calculators, then in contacts with publishers, stress the need for high-quality materials that incorporate calculator use in meaningful ways.

6. When buying calculators, do not make decisions merely by price. Follow the guidelines in this section.

5.4 COMPUTERS: SOFTWARE

SUMMARY

A school's choice of a computer is relatively unimportant. Far more critical is the selection of computer programs. Ordinarily it is better to select the programs first, and then to choose a computer that is compatible with those programs.

BACKGROUND

The general term *software* refers to any kind of computer program or to a collection of programs. (The word is formed by contrast with *hardware*, used to describe the computer proper and its accessories.) With minor exceptions, software consists of a list of instructions, in code, that the computer follows one at a time. The software determines how a computer operates from moment to moment.

Suppose, for example, that a computer is presenting mathematics problems and keeping track of the student's answers. It is the software that tells the computer how to create the problems, how to put them on the screen, how to take in the student's responses, and how to keep a running tally of right and wrong answers--always one small step at a time. The computer does the work, but always under the detailed instructions programmed into the software. If we analogize the computer to a record player, the software becomes the pattern of bumps and grooves on the record, the pattern that tells the record player what sounds to put forth at each instant. Without the software, the computer can do nothing at all.

A programmer writing software for the first time puts it into the computer through the keyboard and later transfers it to magnetic disk or tape. When purchased by the school, the software comes on the disk or tape, one or the other; they rarely are interchangeable. The software, before it can be used, must be copied from the disk or tape into the school computer's memory, by having the computer "play" the disk or tape. Then, while the computer is running, it can look into its memory at the software for each next instruction as it comes due. Between uses, the software is ordinarily kept on a disk or tape similar to that on which it was purchased.

A second type of software is built into the computer and cannot be changed by the user. This permanent software--computer engineers call it *ROM* for *read-only memory*--consists of instructions that the computer needs for its internal housekeeping and for passing information to and from its innards. Part of the

ROM, for example, contains instructions for performing simple arithmetic. Another part tells the computer how to draw numbers on its screen.

Any piece of purchased software contains instructions written for a particular type of computer. Because the coding of instructions varies from one kind of computer to the next, software ordinarily works only with the make and model of computer for which it was written. Although there are programs to translate software from one computer to another, they are limited in what they can handle and should not usually be relied upon.

EDUCATIONAL USES OF COMPUTERS

Computers serve two very different kinds of goals in education. The role of software is likewise very different in the two, and it is well to keep them distinct.

First, computers can be used to teach about computers. With computers now all but indispensable throughout society, influencing daily life in industry, in business, and at home, educators see an increasing need for students to understand the principles by which they operate. Moreover, facility with computers is rapidly achieving the status of a basic skill, often described as "computer literacy."

There is general agreement that students best learn about computers by actually working with them, and preferably by learning to write programs for them. Accordingly, most efforts toward computer literacy include elementary programming as a major component. Computer literacy, in practice, is largely instruction in creating software.

To create software, however, itself requires software. The permanent software built into every computer determines, among other things, the kinds of programs that students can write on that machine. There is more on this point below in the discussion of computer languages.

The second educational use of computers is to help teach subjects other than computer literacy. This use requires special software that does not come built in; it must be purchased or written. Some publishers refer to software created especially for teaching purposes as "courseware."

Much of the courseware offered to date centers on the teaching of mathematics, and particularly on drilling mathematical skills--mostly because such programs are easy to write. Programs to teach certain topics in physics are similarly straightforward, and many such exist. There are also programs available on the more mechanical aspects of the language arts, such as spelling and punctuation. Within the past few years, courseware on reading and on mathematical problem solving has begun to appear.

With more and more schools acquiring computers, and with the market for courseware increasing accordingly, a minor explosion of courseware offerings is now in progress.

COMPUTER LANGUAGES

All software is written in some *computer language*. Much as the English language might be described as a list of allowable words, together with the rules for stringing them together, a computer language consists of a vocabulary of instructions and a list of rules for combining them.

The hundreds of computer languages divide into two main categories: machine languages and high-level languages.

A program in a *machine language* speaks to the computer directly, with no other processing needed beforehand; machine language consists of the same instructions that the computer uses internally. These instructions are always coded into numbers, most often ranging from zero to 255. A program in machine language consists entirely of such numbers arranged in a long string. If relatively complex, the program might have 10,000 to 20,000 numbers in it.

The actual programming of machine language software is done in a closely related language called *assembly language* which the computer itself translates into machine language in a separate operation. Writing in assembly language is difficult, and only advanced programmers attempt it. Just to divide two numbers, for example, might take several dozen instructions. All the same, assembly language offers great advantages in speed, flexibility, and best use of memory. It is essential for very complex programs and for programs that must run very fast. Video games and word processing programs, for example, are always written in assembly language.

As courseware becomes more complex, more of it will be written in assembly language, converted and sold to the user in the form of machine language. But a machine language program will operate only on a computer that uses the proper instruction codes. Usually, that is a computer of the same type that the programmer used to create the program. Therefore, a school interested in particular machine-language courseware may have to buy a particular model of computer to accommodate it. Purchase of the wrong computer can leave the school very limited in available courseware.

The other type of language, *high-level language*, is the kind that most programmers use. BASIC, FORTRAN, and COBOL are familiar examples. High-level languages are much easier to use than assembly languages, because they provide simple instructions for the operations that people need most often. Dividing two numbers, for example, is as simple as typing in A = 114/12. Finding a square root--which in assembly language

is a major project--becomes just A = SQR(14).

To the computer, however, all high-level languages are foreign. Before it can understand software in a high-level language, it must first translate the high-level language into machine language--into a string of numbers between zero and 255.

Formerly, all computers handled a high-level language program, such as one written in BASIC, in two distinct steps. First, in a step called *compilation*, it translated the entire BASIC program into a machine language program. Second, it carried out the instructions in that machine language program. Large computers still use this process because the machine language version, once it is ready, runs very fast.

Most small computers, however, handle both steps together. The computer takes each BASIC instruction in turn, translates just that instruction into a sequence of machine language instructions, and carries those out. Only then does it take the next BASIC instruction, translate and perform that, and so on through the program. When a program is being translated one step at a time, it runs more slowly than when it has previously been compiled in full into machine language, but for most educational applications the results are fast enough.

Built into the permanent software of most small computers is a special program, called an *interpreter*, that tells the computer how to carry out the step-by-step translation from high-level language into machine language. Such a computer will accept only one high-level language--whatever language the interpreter is designed to handle.

The interpreter language in almost every small computer is some form of BASIC--a language easy enough for elementary students, yet flexible enough for relatively advanced programming. Simple BASIC programs are almost self-explanatory. This one, for example, asks the user for two numbers, adds them, and shows the result:

```
10  INPUT A, B
20  LET C = A + B
30  PRINT C
40  END
```

However, BASIC is not a single, uniform language, just as there are various dialects of natural human languages, there are dialects of computer languages. Different computers, with their different interpreters, accept different forms of BASIC. While all of the dialects bear a strong family resemblance, certain instructions that work in some forms work differently in others, and in still others do not work at all.

Different models of computers, even from the same manufacturer, typically use different dialects.

When the goal is computer literacy, differences in BASIC are rarely grounds for choosing one computer over another. Except for a few that are really just fancy toys, just about all small computers carry a form of BASIC powerful enough for teaching computer literacy through the secondary levels. Sometimes a more advanced BASIC interpreter is an extra-cost option, usually well worth paying for.

A more pressing consideration is that some commercial courseware is written in BASIC. Ordinarily these programs will not work properly unless the school computer uses the form of BASIC for which the program was designed. Translation is sometimes possible, but it can become enormously expensive in both money and time. Again, as with machine language courseware, it is usually best to start with a computer that accepts directly whatever courseware the school wishes to use.

Some computer manufacturers sell their own courseware. The larger independent courseware publishers supply their materials in different versions for different computers. But with dozens of computer models on the market, no publisher can suit all of them. Thus it is often sound practice to make the courseware decisions first, and only then to choose a compatible computer.

COMPUTER LITERACY

Using computers to teach about computers is by far the best developed educational use of these machines, largely because it has been around the longest. In the middle 1950s, only the most advanced technical universities offered programming courses at all. But, just a decade later, most universities had it in the curriculum, as did a few high schools. Ten years later still, in the 1970s, programming was almost universal in the high schools and had begun seeping down into the elementary schools. Today, as computer prices continue to decline, courses in computer literacy are becoming commonplace even in the primary grades.

The software decisions for computer literacy are relatively simple: almost all of the teaching materials available are geared to BASIC, so it is necessary only that the school's computers have BASIC interpreters. Most small computers come so equipped. If the school has several computers, it helps to avoid confusion if they all accept identical forms of BASIC.

A point worth some attention concerns the interpreter's *error messages*. When the interpreter finds an invalid BASIC instruction, as often happens with programs written by beginners, it stops and displays a message. With most interpreters, the message

indicates the program line in which the error occurred. Better interpreters also tell the student, in plain English, what kind of error he made. Clear and detailed error messages can be of enormous help to students in learning how to program.

The most important decisions in computer literacy are not in the computer software, however, but in the teaching materials--the textbooks, workbooks, teachers' guides, and so on. These are chosen by the same criteria as any other instructional materials: objectives, depth and scope of coverage, teacher acceptance, time requirements, practicality of classroom management, cost, and publisher support.

Some courses in computer literacy are themselves offered in the form of computer software. Using these, the student reads text material from the computer screen and performs workbook exercises at the computer keyboard. Some of these on-screen programs are said to have high educational effectiveness. Three factors, however, can mitigate against them: (1) like other courseware, they run only on certain computers; (2) they generally require larger computer memories than a student would need with pencil-and-paper materials, which can push up the equipment cost; and (3) students will have to spend more time at the computer, which often calls for more computers, and hence still greater cost. Note that publishers' estimates of the computer time required are often unrealistically low.

If these factors do not raise a serious problem, then the considerations in choosing such a program become the same as for other courseware, discussed below.

COURSEWARE

The most difficult decisions in computer instruction lie not in the computers, but in the courseware they will use. It is the courseware that teaches, not the computer. It is the courseware that sets up the moment-to-moment interaction between child and machine.

All of the familiar considerations that apply to buying conventional materials apply to courseware as well. Some, especially those relating to classroom management, apply with a special vengeance. The companies now producing some of the available courseware are computer-oriented, rather than education-oriented, and may be unfamiliar with the day-to-day realities of running a classroom. But as the companies gain experience, and as established educational publishers and consortia move further into the courseware business, these problems should abate.

To an even greater extent than with conventional materials, the teachers involved should have a very strong voice in the selection of courseware. See the discussion below on teacher involvement.

In evaluating courseware, it is important for the decision makers themselves to try it out, putting themselves in the students' place. The supplier may be willing to provide samples for this purpose. At the very least, a demonstration should be arranged.

Factors worth considering include the following:

- Educational objectives addressed: the introduction of computers should complement the ongoing curriculum, not require its overhaul
- Pedagogical compatibility with conventional materials that students are using
- Ease of loading programs into the computer and getting them started
- Ease of use: good courseware feels natural from the start; it requires a minimum of special codes, instructions, and symbols
- Pedagogic clarity
- Appropriateness to grade level: especially in materials the student must read
- Responsiveness: every action by the student should draw some sort of response from the computer; and subsequent presentations by the computer should reflect the student's prior performance
- Friendliness: computer responses should be supportive, not intimidating, and geared to an appropriate reading level
- Speed: there should not be waits of longer than a second or two while the program is running
- Flexibility: the computer should respond appropriately, even to unexpected student inputs
- Error protection: it should not be possible to stall the computer, no matter how flagrantly the student disregards instructions (except for initial program loading, which is unavoidably sensitive to user error)
- Style of interaction: the best examples of courseware follow the student's lead, rather than take him in lockstep through a predetermined sequence of exercises
- Documentation: printed matter accompanying the software for both students and teachers should be clearly written and illustrated, as well as easy to use

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- Reporting: the program should make available a summary of students' progress for the teacher
- Supplier support: the supplier should be willing to train teachers, to replace at nominal cost any copies of the program that become worn out or accidentally destroyed, and to make minor program modifications at little or no cost (except for machine language programs, which are difficult to change)
- Cost.

TEACHER INVOLVEMENT

The original impetus for computer use might come from any of several sources: the state, the district, the principal, teachers, parents, or students themselves. However the idea first arises, it is most important that it have the full support of teachers who will be involved. Teachers should have a hand in all of the decisions from the very start, including whether to try computers in the first place, and particularly in any choice of courseware.

On their own initiative, some teachers are enthusiastic about computers. Often these are the people who first urge that the school adopt them. Some teachers are eager to bring in their own computers from home, to write their own instructional programs, and to work with other teachers in expanding computer use. One or two such teachers in the school can be a great asset, and their activities should be encouraged.

Other teachers, however, are suspicious of computers from the beginning. One common reason is unfamiliarity, and the anxiety that it engenders. Another reason, less often articulated, is concern about job security--though experts in the field regard as science fiction any scenario in which computers supplant human teachers. Both of these grounds usually yield to reason, reassurance, and experience. An hour or two at the keyboard, under the guidance of a teacher more familiar with computers, is often enough to make a skeptic into a new convert.

A third reason, and one sometimes offered to save face, is a philosophical opposition based on the belief that children ought to be educated entirely by people, with a minimum of help from machines of any kind. Still, teachers who take this position are often willing to accept computer literacy as a necessary skill in today's society and to support computer use for that purpose. With computers in place to meet that goal, and in the face of student enthusiasm, objections to the use of computers in other subjects may gradually evaporate.

In any event, to impose computers on a teacher who is unwilling or unprepared to work with them, for any reason, is usually a formula for disaster.

RECOMMENDATIONS

1. New computers should not come as a surprise to anyone connected with the school. Let plans be known well in advance to all concerned.

2. It is especially important to inform parent groups early. While some parents may oppose the idea, on either emotional or intellectual grounds, other parents are likely to offer enthusiastic support. Even those parents who disapprove are more likely to go along with the decision in the end if they were able to express their opposition beforehand.

3. When introducing computers into a school for the first time, it is advisable to build a constituency on as broad a base as possible, rather than simply to impose the idea from above. One approach is to form a working committee of interested teachers and parents, and to turn over to them as much responsibility as the circumstances allow.

4. As an initial step, before considering particular software or equipment, it is helpful to list intended educational goals, including subject areas, grade levels, and where possible, specific objectives. The list may change later, according to the software and equipment that looks most promising; but such a list helps to avoid the less satisfactory approach of "Let's get the computer first, and then we'll see what it can do."

5. With goals listed, the next step is usually to examine appropriate software. These are the key decisions and should not be rushed. Well-designed instructional software should list scope and sequence, just as a textbook would. Make certain that these suit the school's educational objectives. Because working with software can be seductive even to seasoned educators, it may be wise to assess the match to objectives before turning to the computer.

6. One possible outcome is a decision that computers will not be of sufficient educational benefit to justify the cost.

7. Try out all software considered. If seriously interested in a package, ask the supplier to provide, for a week or two, a sample copy and a computer to run it on. Some dealers refuse, fearing unauthorized copying. If possible, however, test the software at leisure, preferably in the school building so that all interested teachers can work with it. Check all of the points listed earlier in this section.

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8. Determine, for each piece of software considered, the computers on which it will run, by make and model number.

9. Find out how much computer memory each piece of software requires. Usually this is expressed as 16K, 32K, or 48K. (See Section 5.5.)

10. Determine if the software requires any accessory equipment. Most commonly needed are a printer or disk drive (see Section 5.5), but other equipment may be necessary. This information bears significantly on start-up costs, but some salespeople will not volunteer it unless asked.

11. Be wary of a product whose salesperson says, "Oh, yes, it'll work fine on a Brand Z with just a couple of small changes." Ask if the supplier will make those changes and guarantee the result in writing. Refuse any other reassurances. Refuse especially the claim, "You can hire somebody to fix it for just a few dollars."

12. Obtain prices and offers of delivery dates in writing. Do not buy software of which the salesperson says, "They're working on a much better version that'll be ready in just a week or two." Chances are, it won't.

13. During its first year or two in the field, newly developed software often shows minor defects. Known in the trade as "bugs" or "glitches," these are all but impossible to eliminate completely ahead of time. Most bugs are only a minor inconvenience. A reputable supplier will investigate and correct any that you discover--or, more likely, that your students discover. As a matter of course, he will also provide you with new versions that correct any bugs discovered by other customers. Determine your prospective supplier's policy in this regard. An assertion that "we get rid of all the bugs before we release the programs" is not a satisfactory policy.

5.5 COMPUTERS: HARDWARE

SUMMARY

Wise computer purchases depend on, first, a clear understanding of what the computers will be used for and, second, the goal of achieving those purposes at a minimum of cost and complexity.

BACKGROUND

A generation ago, computers came in only one size--huge--and at prices suited to only the largest corporations and universities. Yet, today's desktop computers hopelessly outclass those early models in performance, at a tiny fraction of their cost.

The evolution of computers took place in four distinct steps, roughly a decade apart. The first practical computers used thousands of vacuum tubes, and in consequence took up too much room and power, put out too much heat, and were not very reliable. The invention of the transistor solved some of those problems. Computer manufacturers changed over during the 1950s, launching the second stage. Prices dropped and computers proliferated.

The third stage came with the combination of several transistors and other components on a single chip of silicon. This development reduced the contents of a circuit board from the size of a book to that of a fingernail. At first, the technology was too expensive for any but missile guidance computers, but its price fell sharply during the 1960s, and again computers shrank suddenly in size and cost.

The fourth and current stage came in the middle 1970s, when engineers were able to replace the many circuit boards of a computer's central circuitry--in effect, everything but the memory--with one extremely complex silicon chip. That made possible the microcomputer, the familiar self-contained desktop unit with its built-in keyboard and display screen.

Further changes are in the offing. New silicon chips include not only all of the computing circuitry, but a great deal of memory as well. One manufacturer now sells a full computer, complete with keyboard and a one-line display screen, small enough to fit in a suit pocket. Retailing at $250, it accepts programs in BASIC (see Section 5.4) and can do almost everything that a desktop model does.

The changes noted above were in *hardware*, in the physical makeup of the computer, as

distinct from its software, or programming. But software developments kept pace. As computers became more complex, so did the programming. Paradoxically, the more elaborate programming made computers far easier to use, to the point where one can use a modern computer for hundreds of different purposes without knowing anything at all about computers. The user needs only a few minutes of instruction in how to load and start the programs, which is about as hard as operating a stereo system. Some small computers will handle even that by themselves.

Because their use has become so simple, many computers nowadays are purchased by people who know nothing about them. Educators increasingly find themselves in this position. Accordingly, the notes to follow provide some needed information.

INTERCONNECTIONS

There are five basic ways in which users can share computing facilities:

- *Batch processing.* The user drops off his programs and data at a central facility and picks them up the next day, rather as though having his laundry done. Once this was the only method available, but now it is used only with very large, specialized machines.
- *Time sharing.* Users sit at *terminals* connected to a central computer. Each terminal has a keyboard and display screen, but computing power comes from the central facility. All users can work with the central computer more or less simultaneously. One large-scale educational system, called PLATO, uses this approach.
- *Stand-alone.* Each user works at his or her own computer. This is the approach most often adopted for educational purposes.
- *Large network.* Each user has a complete computer, but the computers are interconnected so as to share programs and data. There are two large commercial networks that users can access through the telephone system, but education has not been among their major priorities.
- *Local network.* Using equipment also suitable for stand-alone use, it is possible to connect a teacher's computer with up to about thirty-two student computers, using special equipment. This enables the teacher to set levels of difficulty individually, for example, and to monitor student progress.

Of the five possibilities, and leaving PLATO aside, the vast majority of educational applications use individual computers standing alone. That is the approach we focus on here.

TYPES OF COMPUTERS

Computers have no orderly taxonomy. Even the division between "business" and "personal" computers is more a matter of marketing than of technology. In fact, more so-called personal computers are used in business than at home. This is also the category most often chosen for school use.

The *microcomputer*, the kind in most schools, no longer represents a distinct category. Very roughly, the term applies to a computer having its electronics in the same case as the keyboard. It usually has a built-in display screen, though some connect to a separate television set. Recently, however, several manufacturers have introduced very powerful business machines that fit this description, some of which can replace a refrigerator-sized *minicomputer*. Thus, the term microcomputer is no longer very specific.

A more useful classification of computers is by *byte size*, a concept that rests on how the computer handles information. To process any information at all, computers must first convert it into numbers. Even letters of the alphabet and punctuation marks are represented as numbers, usually according to a standard code called "ASCII." Capital "A," for example, takes ASCII code number 65.

For reasons of electronic convenience, all numbers inside the machine are formed using only 0s and 1s. Sixty-five, for example, is represented as 010000001. Each 0 or 1 is called a *bit*, rather than a digit. The computer handles all information in the form of bits.

The computer does not, however, handle only one bit at a time. That would be too slow, by computer standards. Instead, it processes several bits at once, in a group called a *byte*. In most small computers, one *byte* consists of eight bits. Such computers are called eight-bit machines.

Eight-bit bytes are not the only possibility. Most of the newer business microcomputers use sixteen bits instead, and thirty-two-bit microcomputers are not far off. Both are much faster than eight-bit machines, and can handle much more memory. They also cost much more. In contrast, some of the least expensive computers use four-bit bytes, and so are slow and limited in what they can do.

The large majority of educational software now available is geared to eight-bit machines. That may change, as the price comes down on sixteen-bit computers. For now, however, and probably for several years to come, an eight-bit computer is the best choice for educational use.

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Some eight-bit computers have their own display screens, and some provide for connection to an external television set. The type without a screen is less expensive, but it is not a good choice. For one thing, it ties up a television set. But more important, the picture on a separate television screen is coarser and less steady than on a built-in screen. The difference may be hardly noticeable at first, but it quickly becomes fatiguing to the user.

Another distinction among small computers lies in the type of keyboard. Most computers use a keyboard much like that on an electric typewriter, with separate keys that move down when pressed. These are called *full-travel keyboards*. Some, however, especially at the lower end of the price range, have *membrane keyboards*, which consist of one smooth sheet of plastic with the letters printed on. Each region of the plastic, when pressed, puts the corresponding letter on the screen, usually with a "beep" sound.

The chief advantage to a membrane keyboard is its relative indestructibility. As it will survive rough handling and much dirt, it is a good choice for very young students. Typists with any experience, however, find membrane keyboards very slow and awkward to use, making the full-travel keyboard better suited to secondary students. If the computer will be used by school personnel for any administrative functions, then a full-travel keyboard is essential.

Some computers are capable of fancier graphics than others, a point manufacturers stress in their advertisements. Elaborate graphics can be a useful teaching aid in some subjects, if the courseware developers know how to employ them wisely. In much of the available software, however, graphics are used more for razzle-dazzle effect than for serious teaching. The same comment applies to sound effects, discussed further in Section 5.6.

Computers vary in their cabinetry. The important issue, apart from attractiveness, is how much equipment the cabinet holds. The earliest popular microcomputer had separate boxes for its keyboard, screen, printer, disk drives, and extra memory, all hooked together by a tangle of wires. The same manufacturer now puts everything but the printer into one case. Most other manufacturers use two or three. Fewer separate components mean fewer wires to become unplugged accidentally, easier installation, and simpler disassembly for moving or storage.

A final consideration here--there are more below--is the extent to which the computer can later be expanded. As new and better software becomes available, many schools will want to upgrade their computers to accommodate it. Expansion is relatively simple if the computer is designed for it from the start. Otherwise, it may be

necessary later on to replace the computer completely, or else to forego new software developments.

Nearly all manufacturers advertise their computers as being expandable. That is a matter of degree. At the very least, make certain that any computer purchased will accept a parallel printer, a disk drive, and a device whose only name is "RS-232." All three are discussed in Section 5.6.

INSIDE A COMPUTER

Explanations of how a computer works traditionally divide the harware into three main parts: the devices for input and output; the memory; and the central processing unit, or CPU.

The *input/output devices* (I/O) serve to pass programs and data into the computer or out of it. Two I/O devices come built into most microcomputers: the keyboard and the display screen. Besides those, nearly all machines also have either a cassette recorder or a disk drive. For educational uses, one or the other of these is essential. Many other input/output devices are available (see Section 5.6).

The second major component is the *memory*, which stores several very different kinds of information. In the memory, too, all information takes the form of numbers, and all numbers are represented as 0s and 1s.

While the computer is running, the memory holds the program, or software: a list of instructions, coded into numbers, that tell the computer what to do from moment to moment. (See Section 5.4.) The memory also holds any data that the computer is using. In a program that drills arithmetic, for example, the student's answers become data. They go into the memory for comparison with the right answers, also held in the memory.

There are two distinct sections of memory, and they operate very differently. The contents of one section are set permanently at the factory, and cannot be changed by the user. Referred to in Section 5.4 as *permanent software*, its technical name is *read-only memory*, or ROM.

Most of ROM contains a long *interpreter program* for translating the user's programs into the machine's internal language. The next biggest part tells the computer how to draw letters and numbers on the screen. The rest holds routine instructions that the machine uses relatively often. The computer turns to these automatically when it needs them, and ordinarily they are of no concern to the user. Indeed, most users, except for very advanced programmers, need pay no attention to ROM at all.

In the second major section of memory, the contents change while the computer is running. For historical reasons this section is called *random access memory*, or RAM. A common slang term for it is *core memory*, because in early computers it consisted of thousands of tiny magnetic cores.

RAM in turn is divided into two parts. One part holds the user's programs and data, as mentioned above. The other part is set aside for the computer's own use, where it takes part in a wide range of housekeeping functions. Here, for example, the computer keeps track of where it is in the program, and of what information is currently displayed on the screen.

When buying a computer, it is usually possible to order varying amounts of RAM. There is a separate discussion of this issue below.

Some models have yet another kind of memory, via a slot that accepts an interchangeable plug-in device. This is actually a separate ROM, containing a permanent program. Home video game machines are a familiar example of the approach. Computers with this facility offer little plug-in educational software.

The computer's third major component is the *central processing unit*, or CPU. In most machines it is the most complex piece of circuitry. When all parts of the CPU are located on one silicon chip, the CPU is called a *microprocessor*. One definition of a microcomputer turns on its use of a microprocessor, as opposed to having the CPU spread over several components.

It is the CPU that responds to all instructions in the software. Most of the instructions to the CPU and, hence, most of what the CPU does fall into these categories:

- fetch a number from a particular place in the memory
- change a number (for example, by adding or subtracting with another number)
- store a number in a particular place in the memory
- pass data to and from the input/output devices
- skip to another part of the program.

In a high-level language such as BASIC, many other kinds of instructions are possible. But, as explained in Section 5.4, the computer must translate the BASIC instructions, before it can act on them, into machine language instructions. The resulting instructions in machine language are those to which the CPU responds. Because the CPU operates in small, simple steps, even a relatively simple program may take several thousand of these instructions.

Most CPUs handle their instructions quickly, however. In a typical eight-bit microprocessor, the CPU will run through perhaps 100,000 to 200,000 instructions every second. Thus, even a long and complicated sequence goes by in the blink of an eye. BASIC programs seem to run more slowly, because each BASIC instruction must be translated into CPU instructions before execution. (See Section 5.4.) That process, too, is guided by CPU instructions permanently stored in ROM. But it is still so fast that many BASIC programs run as fast as the operator can work the keys.

HOW MUCH MEMORY?

Computer salespeople make much of their products' memory capacity. That should be a minor issue, however, because memory is relatively inexpensive. Ordinarily it is best to buy a computer with as much memory as it can accommodate.

In ordering ROM, there are usually two options at most: a small ROM that handles only a simple form of BASIC, and a larger ROM with a more elaborate BASIC. Always order the larger ROM. Most commercial software will require it, and it makes writing programs much easier for computer literacy students.

The amount of RAM in a computer is more flexible. The amount is designated by a number ending in "K," the usual options being 4K, 16K, 32K, and 48K. This number generally refers only to *user RAM*--that is, the amount of RAM left over after the computer has taken what it needs for housekeeping purposes. In other words, this is the amount of memory available for storing the user's programs and data.

The letter "K" is an abbreviation for *kilobyte*, which under the usual metric conventions would mean 1,000 bytes. For technical reasons, however, each K is slightly more, actually 1,024 bytes. Recall that in most microcomputers, each byte consists of eight bits. One K thus stores 1,024 x 8, or 8,192 bits. A 48K RAM, the largest available on most eight-bit machines, holds 48 times this amount, which is 393,216 bits of information.

How much information is that? When storing text, such as the words in a math problem, the computer needs one byte (not bit) for each typewritten character. An ordinary double-spaced page has about 1,500 characters, which means that a 48K computer will hold about 33 such pages.

The program instructions take up some room, although the computer stores them in abbreviations to save space.

And numbers that are used for computation, unlike numbers in text, are coded into a very compact form. In practice, a little memory can hold a great deal.

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Still, RAM is about the least expensive part of a computer. When ordered with the computer initially, each 16K costs about $100, which works out to just over half a cent per byte, or thirteen bits for one cent. The price is a little higher if extra RAM is added later.

An eight-bit CPU can handle a maximum memory of 64K, ROM and RAM combined. The larger ROM (if two are available) and housekeeping RAM, between them, take up about 16K. This leaves 48K at most for user RAM. Ordering the full complement of 48K from the start ensures that the computer will be able to handle any software issued for that model, and adds little to the initial price.

ADMINISTRATIVE USES

Many schools consider using the same computer for administrative as well as educational purposes. With available *business software*, an ordinary eight-bit microcomputer makes an excellent word processor, and can easily handle such chores as attendance records, accounting, payroll records, and budget preparation.

When a computer is destined for administrative uses, the hardware demands become somewhat stricter. It will definitely need a full-travel keyboard and built-in display screen. It should also have the maximum available memory, because some business programs will require it. Certain peripheral equipment will also be necessary, most often a printer and at least one disk drive (see Section 5.6).

RECOMMENDATIONS

1. Before considering particular hardware, make preliminary decisions as to these three uses: teaching computer literacy, teaching other subjects, and administration.
2. Before looking at hardware, investigate the software available. There are materials for computer literacy and business software to suit any popular computer. But particular software for teaching other subjects will be available for only certain makes and models. The computers most widely used for educational purposes are Radio Shack Model III, Apple II, and Commodore Pet, so most independent publishers give these preference in developing materials.
3. Although it may not always be legal, depending on your contractual arrangements with the supplier, it is common practice for educational users to share software among schools. If you plan to do so, it will be helpful to determine what computers are used in other schools nearby.
4. Most educational users should give first priority to eight-bit computers. These presently represent the best compromise between price and performance, and

collectively they suit most of the available software. It should be at least a few years before the prices come down on sixteen-bit machines, schools begin to buy them, and the educational software developers catch up.

5. Do not automatically buy a manufacturer's latest model, because the widest choice of software is not usually available for a particular model until it has been on the market for two or three years. Some manufacturers, however, make their newer models *downward compatible*, which enables them to handle programs written for the older machines. In that event, there may be a lot of software on the market that can run on the new machine. Be suspicious, however, if the salesperson says that the older software will need "a few changes."

6. As a rule, it is better to choose a model with a full-travel keyboard and a built-in display screen. Exception: units intended mostly for very young children may survive longer if equipped with membrane keyboards.

7. Check *graphics capability*. Usually this is expressed as two numbers multiplied, such as 127 x 47. The numbers indicate how many independent areas on the screen the computer can light up, horizontally and vertically. The bigger the numbers, the more detailed the graphics can be.

8. *Color capability* provides for more elaborate graphics, but it has drawbacks. If the computer connects to a separate color television set, it will give a relatively coarse and unsteady picture, and thus will make textual material tiring to read. A built-in color monitor gives a much better image, but adds considerably to the equipment costs. Black-and-white is probably sufficient for most educational purposes, and is the better choice when funds are very limited.

9. A unit that is self-contained in one cabinet will be easier to install and relocate than one in several separate cases.

10. Check expandability. As the minimum, be sure that the computer can accept a parallel printer, a disk drive, and an RS-232--unless, of course, these are installed initially (see Section 5.6).

11. On the screen, look for a clear, steady, detailed image, in sharp focus from edge to edge with no shifting or squirming.

12. A keyboard that feels mushy is a sign of poor manufacture. Key action should be crisp and smooth. Each key should hit a definite bottom.

13. Computer keyboards have a natural tendency to put double and triple letters on the screen, a phenomenon known as *key bounce*. There is a short program in ROM to

prevent this. A computer that shows any key bounce will be very frustrating to work with, and should be rejected.

14. If the manufacturer offers two ROMs with different BASIC interpreters, the larger is usually the better option.

15. It is usually best to buy the full complement of RAM at the outset. This will be either 48K or 32K. Do not go below 16K--most software needs at least that much--and, if buying less than the maximum, make sure that more memory can be added later.

16. If the computer will be used for administrative purposes, choose a model with full-travel keyboard and built-in screen. Order full memory. You will also need a printer, and most likely at least one disk drive (see Section 5.6).

17. Make certain that repairs are available locally. While the computer itself is unlikely to give much trouble unless abused, any peripheral equipment with moving parts, especially printers and disk drives, may need occasional service.

18. When comparing prices, be sure to match machines that are similarly equipped. For price comparisons only--it may not be the system you want to buy--most dealers can quickly quote a price on this configuration: built-in screen, full BASIC, 16K RAM, and (a) with cassette recorder, (b) with one disk drive. Ensure that prices quoted include any necessary cables and installation charges, sometimes costed separately. Price printers separately, as they are easily interchangeable among computer brands. It is unwise to mix brands when buying disk drives, however, because the electronic marriage between disk drive and computer is quite complex.

19. Some dealers are willing to lease equipment. Depending on the school's financial posture, leasing may be preferable to purchasing. Note, however, that the dealer may require that you take a service contract as a condition of the lease. These contracts are sometimes overpriced. Unless you plan to take the service contract anyway, figure it into the cost of the lease. The lease agreement should enable you to buy the equipment outright at the end of the lease period for its "salvage value," an amount that should be written into the agreement.

20. Some manufacturers provide a toll-free hot-line for users who encounter trouble. A valuable service, this is usually worth a slightly higher initial equipment cost.

5.6 COMPUTERS: PERIPHERALS

SUMMARY

Peripherals are accessory devices that attach to a computer. They can greatly extend its efficiency and effectiveness.

BACKGROUND

Without accessories, a microcomputer has certain limitations. It can accept information from the keyboard, process it, and display results on the screen--but that is all. It cannot put its results on paper, or hold information once the power is turned off, or exchange programs with other computers.

These shortcomings and others can be remedied by attaching peripheral devices to the computer. Ordinarily the computer comes without them, so that purchasers may assemble just the devices they require and so keep costs to a minimum. Most applications, including educational uses, require some peripherals from the outset. Others can be added later, if needed.

Attaching all but a few peripherals is simply a matter of plugging them in to the computer. To make each peripheral work with as many computers as possible, manufacturers offer several different cables to make the connection. When buying a peripheral, it is usually necessary to buy also the cable that attaches it to your particular machine.

Computer manufacturers supply many of the peripherals for their own machines. Many other companies make only peripherals. For some items, industry standards assure that products from different manufacturers will work together properly. A printer or cassette recorder, for example, will usually combine with a computer made by a different company. Some other peripherals are not as well standardized; and for those, it is safest to buy from the computer manufacturer.

EXTERNAL STORAGE

Needed in almost any educational application is some way to store programs. Computer literacy students should be able to keep their programs from each session to the next, or they will spend valuable time at the computer just retyping in yesterday's version. The school's computers must also be able to read courseware in other subjects.

The two most common methods of storing programs use ordinary audio cassette tapes and

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special magnetic disks called *floppy disks* or *diskettes*. A third method, suited only to fairly large systems, uses a *hard disk*.

The choice is ordinarily between cassettes and floppy disks. A *cassette system* is by far the least expensive. Its main disadvantage is the time required to load a program. Depending on the length of the program and the speed of the system, that can range from less than a minute up to fifteen minutes or so. *Disk systems* are much faster. They can load even a long program in just a few seconds, and they store programs somewhat more reliably. But the *disk drive* that plugs into the computer costs several hundred dollars, compared with fifty dollars or less for a cassette recorder. For courseware that comes only on disk, however, a disk drive will be essential.

Cassette users can hook their own recorder to the computer, using a special cable provided by the computer manufacturer. One end of the cable goes into a special jack in the computer; the other end has the standard plugs that most recorders accept. Any recorder capable of providing clear sound will do. Those with a "remote jack" are easier to use, as the computer can then start and stop the recorder by itself as needed. There are special cassette tapes for use with computers, but any high quality audio cassette works just as well and costs less.

One characteristic of the computer important to cassette users is the rate at which it transmits information to and from the cassette recorder. This is expressed as a number followed by the word *baud*, which means "bits per second." (See Section 5.5.) A higher baud rate will load programs faster, and will use less tape for the same program. Baud rates ordinarily range from 250 to 1500.

The computer should be able to *verify* tapes--that is, to play back a just-recorded tape and make sure that it actually contains the same information that the computer tried to record. Note that tapes made on one computer will not ordinarily load into another of differing make and model. Apart from difference in baud rate, different computers code information onto the tape differently.

For schools that can afford them, disk drives are a better choice, owing to their much greater speed. The disk drive comes in a separate box that plugs into the computer, except that one manufacturer mounts the drive in the same cabinet, next to the screen. Usually the computer itself needs additional circuitry to handle the drive. There may be a charge for installation, unless the drive is initially ordered with the computer.

The disks themselves are either 5-1/4 or 8 inches in diameter, with the larger size

used mostly in business machines. They are made of plastic, coated with a magnetic substance much like that on magnetic recording tape. The disk comes in an envelope. The user simply slides the disk, envelope and all, into a slot in the disk drive. The drive spins the disk at high speed, and reads off the information it needs. The same drive can also record programs or data onto blank disks. Depending on the system, it will usually put between 50,000 and 150,000 bytes (approximately) on one 5-1/4 inch disk. (See Section 5.5.) Most small computers can accommodate up to four drives, but one or two is usually enough.

When buying several computers, it is possible to equip only one with a disk drive, and to interconnect it with the others so that the unit with the drive can transmit programs back and forth to those without. One manufacturer charges $850 for a disk drive, but only $600 for a device to interconnect sixteen other computers to the machine with the drive. The same device also lets the sixteen computers share a single printer (see below). Some other manufacturers offer less expensive drives, so this may not be the most economical solution with only two or three computers.

Mechanically complex and built to very precise tolerances, disk drives are the component in the system most likely to need service. Be very certain that repairs for the disk drives you choose are available nearby.

The ultimate in external storage is the hard disk, which is extremely fast and extremely reliable. Unlike a floppy disk, which can be taken out of its drive mechanism and replaced with a different one, a hard disk is built into its drive permanently. Because it holds several million bytes of data or program, there is no need to change it. One unit will cost at least a few thousand dollars, however, making it most practical where a dozen or more computers can share it. In a large system it is less expensive than several floppy disk drives and gives much better performance.

PRINTERS

A printer provides *hard copy*--computer output on paper. Most courseware does not need printers for student work, although some courseware does require them for making reports to the teacher on student progress. Printers are generally essential either for teaching computer literacy or for administrative uses.

A computer printer that puts out a full-sized page, as most do, is called a *line printer*. These machines can be categorized in four major respects.

First, some printers provide characters that look very much like those from an office typewriter. Called *daisy wheel printers*, they are relatively expensive, typically

in the neighborhood of $2,000. The other major sort, called *dot matrix printers*, form their characters with tiny dots; the printed output unmistakeably looks like it came from a computer. Dot matrix printers can cost a good deal less than daisy wheels, and are ordinarily sufficient for all except office word processing applications.

Second, printers are either *serial or parallel*. Recall from Section 5.5 that it takes one byte, or eight bits, to encode a typewritten character. (More precisely, only seven bits are so used; depending on the system, the eighth bit either tells the printer that the other seven indeed carry text to be printed, or else it is ignored.) A parallel printer accepts all eight bits for each character simultaneously, while a serial printer takes them one at a time. Serial printers require that the computer be equipped with an RS-232 (see below), and they need the execution of special instructions before printing can begin. Ordinarily a parallel printer is the better choice.

Third, printers vary widely in speed. Specifications for printing speed usually appear in *cps*, or characters per second. Daisy wheel printers are slow, typically at about 30 cps--roughly one minute for a double-spaced page. Inexpensive dot matrix printers go at about the same speed, but cost much less than a daisy wheel. Faster dot matrix units run up to several hundred cps, but the price goes up along with the speed. For educational use, speed is rarely an important factor.

The fourth distinction, less important than the others, concerns how the printer pulls its paper. Some, called *friction-feed printers*, simply squeeze the paper between rollers. These use paper that comes in inexpensive rolls, but they have a tendency to slip and jam. A better kind, using special paper with holes punched down the sides, grabs the paper with studded rollers. Still others, mostly high speed printers, use the same punched paper, but pull it with an accessory device called a *forms tractor*.

There are other factors by which to judge a printer, including cost, noise level, durability, availability of ribbons, and access to repairs. For most educational applications, the best choice is probably a relatively slow (and hence inexpensive) parallel dot matrix printer that uses punched paper without a forms tractor. Some very low-priced units that fit this description may not be durable enough for school use, but several companies make satisfactory machines in the $500-700 range. One printer is usually enough to serve several computers.

COMMUNICATIONS

With the appropriate equipment, computers can communicate with one another and with an expanded range of peripheral devices.

The key component in computer communications is a device known as an *RS-232*. This designation, strictly speaking, refers to the standard electrical codes for passing signals between computers. For want of a better name, the device that translates information to and from those codes is also called an RS-232.

The RS-232 is a circuit board that mounts inside most computers. It must be professionally installed. It is, in some respects, a small computer in its own right, and it must be specially programmed before each use. This programming tells the RS-232 which of the available codes it is to use. When two computers are communicating, their RS-232s must be programmed identically. When one computer is using an RS-232 to communicate with a peripheral device--a serial printer, for example--the RS-232 must be programmed to fit the device's requirements.

Computers located close to one another can be made to exchange programs and data directly, merely by wiring their RS-232s together through cables sold for the purpose. This arrangement is sometimes used in classrooms.

For more distant communications, the RS-232 attaches to a separate device called a *modem*, which plugs into the telephone lines. The modem converts the RS-232 signals into electrical beeps which can pass over the telephone system. At the other end, a second modem converts the beeps back into RS-232 signals, which it hands over to the receiving computer's RS-232.

Schools not contemplating an application that requires RS-232s usually need not order them at the outset. They can always be installed later, if the need arises.

SOUND

Some computers come equipped for sound effects, and some of the software written for those computers takes advantage of the capability. Because they are easy to program, the sound effects ordinarily resemble the beeps and whistles familiar from video games. Software developers who use sound claim that it helps student motivation and concentration.

Any computer that accepts a cassette recorder--most small computers do--can put out the same sound effects, with the addition of a $10 amplifier/speaker. Even the companies that make such computers have been slow to realize this fact and to take advantage of it. Ultimately, then, sound capability rests more in the software than

in the computer. Sound effects should not be a basis for choosing one computer over another, except insofar as preferred software runs on some computers and not on others.

A promising development in the past few years has been the addition of speech capability to computers. One manufacturer offers a speech device as a standard accessory, but similar devices can be attached to other computers as well. Most speech devices require an RS-232.

The speech that these devices put out is easily understandable, but the quality is not pleasing to every ear; it sounds rather like the popular conception of a talking robot. For very young children, however, and for older students whose reading skills are limited, computer speech can make time spent with the machine much more productive than it might be otherwise. Again, effective use of speech depends ultimately on the software.

RECOMMENDATIONS

1. If finances permit, equip at least one computer with at least one floppy disk drive. Otherwise, it will be necessary to have cassette recorders. Note that much of the commercial courseware is not available on cassette, and its use requires a disk drive.
2. In a large, interconnected system, consider the purchase of a hard disk. While expensive, its performance will often justify the cost if it serves enough computers.
3. Except when buying disk drives and RS-232s, shop around for peripherals. Good equipment that works with your computer will often be available from independent manufacturers at prices substantially below those charged by the computer manufacturer.
4. Most systems will need at least one printer. Unless the system will also be used for office word processing, a dot matrix printer will suffice. Choose a parallel printer, if a suitable one is available, and be sure to buy the right cable for your computer.
5. Before buying a dot matrix printer, check a sample of its printed output. The type from some printers is far more readable than from others.
6. Because of their many moving parts, printers occasionally need repair. Be sure that service is available locally.
7. Ribbons for some of the less common printers can be difficult to obtain. Make sure that the ribbons your printer takes are a standard office supply item.

8. If you expect to need RS-232s, order them initially, as this may save on installation charges.

9. Instructions for programming an RS-232 can be difficult to follow. If this is the case, ask the dealer to type out simplified instructions for your particular application.

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